

PROCEDURES FOR RADIANCE CALIBRATION OF A RADIOMETRIC SPHERE SOURCE

Purpose

This document describes the methods used by GSFC's Calibration Facility (CF) to calibrate large aperture radiometric sphere sources for radiance, using a spectroradiometer and a secondary lamp standard that is calibrated to a NIST standard FEL irradiance lamp.

The calculation of the spectral radiance of a large-area sphere source is a three-step process, based on spectral irradiance measurements. First, a standard irradiance lamp is measured by the spectroradiometer. Then the spectroradiometer is used to determine the spectral irradiance of the large-area sphere source. Finally, the spectral radiance of the sphere source is calculated using the source measurements combined with the geometric parameters of the setup.

Equipment

Spectroradiometer system –

The CF uses an Optronic Laboratories (OL) Model 746 single grating monochromator. The 746 features a choice of detectors, selectable entrance and exit slits and order sorting filters, a precision transimpedance amplifier, integrated chopper, and phase sensitive detection electronics. A 10.2 cm diameter BaSO₄ coated integrating sphere with a 2.54 cm diameter input aperture is affixed to the entrance slit. A grating carousel permits selection of one of three gratings to cover a broad spectral range. The spectroradiometer operation is automated using a computer running a control program that was developed by OL and later modified by the CF. Further details of the configuration and operation of the 746 spectroradiometer can be found at <http://spectral.gsfc.nasa.gov>.

Irradiance transfer lamp and power supply –

The CF uses a NIST standard FEL lamp and the 746 spectroradiometer to transfer The NIST irradiance scale (NIST irradiance data) to a Hoffman FEL type 1000 W tungsten/halogen lamp. The Hoffman lamp is then used as a working standard for further radiometric calibrations. An OL Model 83-A standard lamp power supply is used to power the standard lamp.

Radiometric source descriptions –

The sources currently calibrated on a monthly basis at GSFC include a six-foot diameter sphere, a four-foot diameter hemisphere, and a 42-inch diameter Spectralon Labsphere source. Each source is internally illuminated by up to 16 baffled lamps positioned uniformly along a vertical circumference surrounding the entrance aperture of the source. The six- and four-foot diameter sources are coated inside with barium sulfate paint; the Labsphere source consists of flat polygonal Teflon plaques arranged in a spherical buckyball configuration.

Power system –

For each sphere source, banks of lamps are controlled by precision current source power supplies. Once the source has stabilized at the maximum level (all lamps on), various lower radiance levels are achieved by turning off lamps in a prescribed pattern. Additional information regarding the operations and descriptions of GSFC's radiometric sources is at <http://spectral.gsfc.nasa.gov>.

Setup for alignment

To sequentially observe the standard lamp and the target source, the spectroradiometer is mounted on a platform that can rotate 90 degrees. The platform is mounted on a small, portable optical table placed near the source aperture. This entire setup is in turn set upon an elevator-table.

A lamp mount is positioned on a post attached to an optical rail, which is attached to the optical table. Adjustments to the rail and the post height allow translations along three orthogonal axes. The lamp mount can be rotated about the long axis of the lamp filament.

With this configuration, the spectroradiometer can be independently aligned to both the lamp and sphere source to allow quick targeting during the calibration. First, the standard lamp is aligned and set at the correct distance from the spectroradiometer. Then the spectroradiometer is rotated, and the entire optical table is moved to align the spectroradiometer so that it targets the sphere source, without affecting the alignment of the lamp.

Standard lamp alignment

To facilitate lamp alignment, a post-mounted lamp alignment jig is placed in the lamp mount on the optical rail. The jig has a glass slide with scribe lines to indicate the center of the lamp's filament. Using an attached alignment laser affixed 90 degrees to the monochromator entrance slit, the jig center is aligned to the laser defining the nominal optical axis of the input sphere. Retroreflection of the laser from the alignment jig assures that the jig is normal to the optical axis. The input sphere is replaced and the alignment jig is positioned along the optical rail at the calibration distance (nominally 50 cm) from the input sphere aperture. A system of baffles is placed midway between the input sphere aperture and lamp mount to limit scattered light reaching the input sphere.

Sphere source alignment

The central optical axis of the sphere source aperture is aligned with the input optical axis of the spectroradiometer, using the attachable alignment laser. The mounting platform is rotated to direct the spectroradiometer input sphere aperture toward the source aperture. The alignment laser is attached and leveled to target the source aperture. The optical table height and position are adjusted until the input sphere and source apertures are parallel and coaxial. This is indicated by use of targeted aperture crosshairs and retroreflection of the laser from a plane mirror placed on the source aperture cover (or aperture edge, if this is parallel to the plane of the source aperture). The input sphere is then replaced and leveled, and the distance from the input aperture to the source aperture is measured and recorded. To insulate the spectroradiometer from heat radiated by the source, a baffle is put directly in front of the spectroradiometer (but not obscuring the input sphere's view of the source aperture).

Blocked source measurement

The blocked source measurement is a measurement of all light not travelling directly from the sphere source aperture to the input sphere aperture. This includes ambient room light and scattered light from the source itself. To perform the blocked source measurement, the sphere source is slowly ramped up to its highest lamp level (all lamps illuminated). So as to obscure any light radiating directly from the source aperture, a round baffle 10 cm in diameter is placed directly in front of the input sphere, approximately 3 cm from the aperture. The spectroradiometer system then records the ambient and scattered light in the room over a wavelength range within the limits of the standard lamp's calibration.

Source measurement

The blocked-source baffle is removed. The output of the source is measured with the spectroradiometer input sphere aperture aligned toward the source aperture. Measurements of the sphere source output are then taken, using the same wavelength range and intervals used when making blocked source measurements.

Lamp measurement

To provide signal-to-irradiance conversion factors, measurements of the output of a standard lamp are taken after the source measurement. The spectroradiometer is rotated 90 degrees so that the input aperture is directed toward the previously aligned lamp mount. A standard lamp calibrated for spectral irradiance is placed in the mount and slowly ramped up to the calibration current of 8.20 Amps, as measured by the lamp's calibrated constant current power supply. Additional black baffling material is also used to reduce ambient light from the sphere source and scattered light from nearby and background surfaces. After the lamp has stabilized at 8.20 Amps for approximately 10 minutes, the spectroradiometer measures the output of the lamp using the same wavelength range and intervals used when making source measurements.

Additional source measurements

In order to calculate system drift, a source measurement is usually performed directly following the lamp measurement. The lamp level and wavelength range and intervals are duplicated. Additional source

measurements are also taken for lamp levels below the highest level. Typical measured lamp levels for the sphere source are realized with 16, 12, 8, and 4 lamps illuminated.

Interpolating standard lamp irradiance

The CF uses the NIST-developed Planck-polynomial fit for calculating the spectral irradiance of the standard lamp for wavelengths at measured ranges and intervals between the NIST-calibrated wavelengths.

Calculating source irradiance

If the irradiance of a standard lamp, set 50 cm from the spectrometer input aperture is interpolated at wavelength λ , then the formula for irradiance from a radiometric source is:

$$Es_{\lambda} = (El_{\lambda} / Sl_{\lambda}) * (Ss_{\lambda} - Sb_{\lambda})$$

Where Es_{λ} is the irradiance from the sphere source at wavelength λ , and El_{λ} is the irradiance from the standard lamp. Sl_{λ} is the measured signal from the spectrometer of the standard lamp, Ss_{λ} is the measured signal of the sphere source, and Sb_{λ} is the measured signal of the non-direct light from the blocked source.

Calculating source radiance

The formula for source radiance is:

$$Ls_{\lambda} = Es_{\lambda} * K$$

Where Ls_{λ} is the radiance of the sphere source at the highest lamp level, Es_{λ} is the irradiance from the sphere source, and K is a calibration constant obtained from the geometry of the source/spectroradiometer setup.

$$K = (a / b)^2 / F * \pi$$

K is the calibration constant, a is the radius of the spectroradiometer's input aperture, and b is the radius of the source aperture. F is a view factor that represents the fraction of radiant energy leaving the source aperture plane that is incident on the plane of the spectroradiometer's input sphere aperture.

The view factor is derived from this formula:

$$F = (Z - \sqrt{Z^2 - 4 * X^2 * Y^2}) / 2$$

Where $X = a / c$ (the ratio of the input aperture radius to the source aperture distance c); $Y = c / b$ (the ratio of the source aperture distance to the source aperture radius); and $Z = 1 + (1 + X^2) * Y^2$.

Calculating radiance for other lamp levels

Signal data from the 746 for other source lamp levels is used in combination with the signal data and calculated radiance of the source at the highest lamp level to determine source radiance for those other lamp levels. A signal ratio (the ratio of the signal of the lower lamp level to the signal of the highest level) is multiplied by the source radiance (at the highest lamp level) to calculate radiance at the lower level:

$$Ln_{\lambda} = (Sn_{\lambda} / Ss_{\lambda}) * Ls_{\lambda}$$

Where Ln_{λ} is the radiance at lamp level n at wavelength λ , Sn_{λ} is the measured signal of the source with n lamps on, Ss_{λ} is the measured signal with all lamps on, and Ls is the radiance of the source with all lamps on.